# Double-Observer Sightability Model Update for Mount Rainier and Olympic National Parks, 2014

U.S. Geological Survey Administrative Report to U.S. National Park Service

**U.S. Department of the Interior**
**U.S. Geological Survey**

**Cover:** Elk in the upper Skokomish Valley, Olympic National Park, Washington. Photograph taken by Patti Happe, Olympic National Park, August 2014.

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SALLY JEWELL, Secretary

**U.S. Geological Survey**
Suzette M. Kimball, Acting Director

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## Conversion Factors

Inch/Pound to International System of Units

| Multiply | By | To obtain |
|---|---|---|
| | Length | |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |

International System of Units to Inch/Pound

| Multiply | By | To obtain |
|---|---|---|
| | Length | |
| meter (m) | 3.281 | foot (ft) |
| kilometer (km) | 0.6214 | mile (mi) |
| kilometer (km) | 0.5400 | mile, nautical (nmi) |
| | Area | |
| square kilometer ($km^2$) | 247.1 | acre |
| square kilometer ($km^2$) | 0.3861 | square mile ($mi^2$) |
| | Mass | |
| gram (g) | 0.03527 | ounce (oz) |

# Double-Observer Sightability Model Update for Mount Rainier and Olympic National Parks, 2014

By Bruce Lubow[1], Kurt Jenkins[2], Patti Happe[3], Paul Griffin[1], and Katherine Beirne[4]

## Introduction

It is well established that not all animals are detected during aerial surveys, and that estimation of detection bias (the proportion of animals not seen during a survey) is key to estimating animal abundance accurately (Pollock and Kendall, 1987). Previously, we developed and published an analysis methodology for double-observer sightability (DO-S) models used to adjust helicopter-based elk survey results for aerial detection bias in Mount Rainier National Park (MORA) (Griffin and others, 2012, 2013). We recently applied this same methodology to summarize trends in the abundance of elk using high elevation summer ranges within MORA from 2008 to 2011 (Jenkins and others, 2015).

The DO-S models were based on detection patterns of two independent observer pairs in a helicopter and on telemetry-based detections of collared elk groups. The models were structured to include effects of specified covariates on the unconditional probability that two pairs of observers in the helicopter (front-seat pair or back-seat pair) detected a given elk group. The DO-S models included parameters that accounted for sighting covariates and for the residual heterogeneity bias that is not accounted for by the explicitly measured covariates. The models were fit to data from two sources: (1) DO-S trials in which two independent observer-pairs aboard a survey helicopter attempted to detect known groups of elk containing one or more radio-marked animals in the group; and (2) double observer (DO) trials of elk groups in which the same observer pairs attempted to locate groups containing no radio-marked animals. The DO trials provided estimates of conditional detection probabilities because the estimated probabilities were conditional upon one or both observers seeing the elk groups. The DO-S trials provided independent data used to estimate the implicit residual heterogeneity bias that would not be quantifiable from DO observations alone, thus producing unconditional estimates of detection probabilities.

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Initially, we planned to develop the suite of DO-S sightability models based on DO-S and DO trials obtained in both MORA and Olympic (OLYM) National Parks so that the resulting models could be applied to adjust survey results for detection bias in both parks. Because of the large-scale failure of GPS-collars (24 of 43) in OLYM, however, there were not enough DO-S trials completed by 2011 to develop the full model for both parks.

Over the last several years, elk were radiocollared in OLYM so that the sightability model could be updated based on a combined set of DO and DO-S trials in MORA and OLYM. In this report, we describe the model development process and the resulting combined models. We then apply these models to update abundance estimates of elk within selected trend count areas (TCA) in both parks. For additional details on the DO-S modeling approach, survey methods, and study area descriptions, and maps the reader is referred to the original publications that described both the DO-S modeling concepts and model development (Griffin and others, 2012, 2013).

## Model Development

We structured 16 candidate models based on 12 variables and 9 two-way interactions between these variables expected to influence detection probabilities (Griffin and others, 2012, 2013, tables 1 and 2). Based on the *a priori* expectation that sightability is likely to differ between parks, we structured all models with a baseline intercept and heterogeneity effect plus additive intercept and heterogeneity parameters for OLYM to distinguish the two parks (four parameters). We reasoned that estimating separate intercept and heterogeneity parameters for both parks would help account for differences in detection probabilities not explained by additional covariates in the model. Examples might include slight differences between parks in flight speeds or patterns, or survey crew sighting efficiencies. Based on high support from models developed previously in MORA (Griffin and others, 2012, 2013) and on the literature (Anderson and others, 1998; McIntosh and others, 2009; McCorquodale and others, 2012; Griffin and others, 2013), we structured all models to investigate each of the following eight effects on detection probabilities in addition to the four parameters described above:

1. The natural log of group size (LnN),
2. An effect of the elk being on the pilot’s side of the aircraft on front-seat detection probabilities (P),
3. An additional effect of the pilot being inexperienced (IXP; defined as fewer than 10 previous surveys of elk abundance in mountainous terrain),
4. A negative effect of the elk being directly under the helicopter on the sighting efficiency of back-seat observers (C),
5. Lighting conditions (L),
6. An additive effect of being a back-seat observer (B),
7. Elk movement (M), and
8. Vegetation density (V).

**Table 1.** Model components considered for inclusion in model structures for detecting probabilities of elk groups in aerial surveys in Mount Rainier and Olympic National Parks, 2008–13.

| Parameter | Interpretation and rationale |
|---|---|
| Int | Common intercept in all models. All other effects are added to this base. |
| OLYM | Additional effect of OLYM (relative to MORA) on detection probability (added to Int). Parks are expected to have different detection probabilities because of factors that are not captured by individual covariates. |
| Hetero | Common effect of heterogeneity biases in all models of both front-seat and back-seat observers in MORA and OLYM. |
| O:Hetero | Additional heterogeneity effect on detection probability at OLYM (added to Hetero). Parks are expected to have different heterogeneity biases because of different observation conditions in the two parks. |
| LnN | Common effect of the natural logarithm of group size for all observations. Group size was expected to affect detection similarly among both parks and for front-seat and back-seat observers. |
| P | Effect of an elk group being on the pilot's side of the aircraft on detection by the front-seat observer pair in OLYM and MORA. Many of the same pilots fly in both parks. The pooled parameter is more general for future changes in pilots. |
| IXP | A further effect on front-seat observers of an elk group being on the pilot's side of the aircraft if the pilot is inexperienced (defined as <10 aerial surveys). The effect of inexperience should not vary between the parks. |
| C | Effect of an elk being directly under the helicopter's flight path on back-seat observer's detection probability. Elk located on the centerline has a strong influence on back-seat detection probabilities and was not expected to vary between parks. |
| L | Common effect of flat lighting on detection probabilities. Elk are more difficult to see in bright light because of contrasting shadows. |
| B | Common effect of being in the back seat on detection efficiency. Even after accounting for the inability to see elk on the centerline, the view of back-seat observers is less than that of front-seat observers because of smaller windows and restricted viewing angles. |
| M | Common effect of movement. Movement might improve detection probabilities if elk have not had a chance to move from the helicopter in response to disturbance before they are sighted, or movement might reduce detection probabilities if movement precedes detection causing elk to move to greater distances where they are harder to detect. |
| V | Common effect of vegetation cover on detection probability. Elk are less easily seen when there is vegetation greater than 2 m tall that obstructs a clear view of the ground. |
| O:M | Additional effect of movement on detection probability in OLYM (added to effect M). Movement may have a different effect on detection probabilities in OLYM because of more recent helicopter capture operations and potentially different movement responses of elk from the helicopter. |
| M*LnN | Additional effect of group size on detection probabilities when elk are moving. Movement might have a larger positive effect on detection probabilities for large groups. |
| V*L | Additional effect of vegetation on detection probabilities in flat lighting. Lighting is expected to affect elk sightability differently in different vegetation, with negative effects of bright lighting and resulting shadows being worse in forest cover. |
| B:M | Additional effect on bac- seat observer detection probability when elk are moving (added to effect M for back-seat observers). If elk are moving in response to the helicopter, the back-seat observer *may* have a greater likelihood of detection because of differences in viewing angles, or a lower likelihood if groups have moved farther away before being available to the back-seat observers. |
| B:V | Additional effect of vegetation on back-seat observers' detection probabilities (added to effect V for back-seat observers). The back-seat observer may have a different probability of detection in vegetation than the front-seat observer because of the different viewing angles. |

| Parameter | Interpretation and rationale |
|---|---|
| O:B | Additional effect for the back-seat observer pair in OLYM (added to other effects for back-seat observers in OLYM). The pool of observers used in the two parks differed. |
| O:V | Additional effects of vegetation cover on detection probability in OLYM (added to effect V for observers in OLYM). Vegetation cover may affect detection probabilities differently in OLYM because the forest communities are not expected to be identical. |
| M*V | Additional effect of vegetation on detection probabilities when elk group is moving (added to effect V when elk group is moving). Elk movement may have a different effect on detection in open than closed vegetation. |
| O:L | Additional effect of flat lighting on detection probabilities of observers in OLYM (added to effect L for observers in OLYM). Initially, we speculated that lighting may have a different effect in OLYM than MORA because surveys are flown at different times of day. |

In addition to the above main effect parameters, we postulated nine interaction effects. Because we saw no reason to suspect that the first four effects in the preceding list would differ between parks, we structured all candidate models to include a single parameter for each of those variables that applied in MORA and OLYM. We hypothesized that the effects of lighting, being a back-seat observer, vegetation, and elk movements could all affect detection probabilities differently in OLYM than in MORA, and formulated parameters for these interactions O:L, O:B, O:M, and O:V, respectively, to represent potential additive effects for those variables in the OLYM surveys. Furthermore, we reasoned there could also be interactive effects of movements and group size (M*LnN), between movements and vegetation (M*V), and that movements and vegetation could have a differential effect on sighting efficiency of front-seat and back-seat observers (B:M and B:V). Lastly, because the bright light creates difficult contrasts in forest environments, we speculated a potential interactive effect of vegetation cover and lighting on detection probabilities (V*L). Our rationale for including each of those effects is summarized in table 1.

Based on these *a priori* expectations, all models were initially structured with 12 main effects, leaving the 9 remaining two-way interaction parameters that could either be included in all models, excluded from all models, or evaluated based on model comparisons. The permutation of models with and without those nine potential effects produced an unmanageable number of models ($2^9$=512 models to be exact). Therefore, we conducted some exploratory analyses comparing model weights for models with and without each of those nine variables. Based on relatively strong support for including the covariates O:M (evidence ratio = 38.1) and M*LnN (evidence ratio = 4.8) combined with plausible explanations for their importance, we decided to include parameters for the effects of those variables in all candidate models. We then fit a set of 128 models with all possible combinations of the remaining 7 parameters either included or excluded to evaluate relative support for each. Based on this analysis, we included the most strongly supported of these parameters (the interaction of light with vegetation, V*L; 62.5 percent of model weight) in all final models. Conversely, based on relatively weak support for an interaction effect between movement and vegetation (27.7 percent of model weight), and for a different effect of lighting in OLYM (27.1 percent of model weight), we decided to omit those variables from all models in the final set. This left four parameters with intermediate support that were evaluated further by structuring candidate models both with and without those four effects. Models with all possible combinations with and without those effects produced our final inference set of 16 models for the analysis (table 2).

**Table 2.** Candidate models results for detection probabilities in elk aerial surveys in Mount Rainer and Olympic National Parks, Washington, 2008–13.

[Models are in ranked order of model support. Explanations of model abbreviations are shown in table 1. An asterisk (*) indicates a parameter included in a given model, a dash (–) indicates a variable not included]. AIC$_c$=Akaikie's Information Criterion with small sample correction.

| | Int | OLYM | Hetero | O:Hetero | LnN | P | IXP | C | L | B | M | V | O:M | M*LnN | V*L | B:M | B:V | O:B | O:V | M*V | O:L | AIC$_c$ AICc | ΔAIC$_c$ Delta AICc | AIC$_c$ weight $W_i$ (percent) | Model Likelihood L | No. of Parameters # P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M1 | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | – | – | – | – | – | 2720.6 | 0.00 | 0.115 | 1.0000 | 16 |
| M2 | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | – | * | – | – | – | 2720.9 | 0.27 | 0.100 | 0.8723 | 17 |
| M3 | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | – | – | – | – | – | – | 2720.9 | 0.29 | 0.099 | 0.8641 | 15 |
| M4 | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | – | – | * | – | – | 2721.3 | 0.74 | 0.079 | 0.6894 | 17 |
| M5 | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | – | – | * | – | – | – | 2721.5 | 0.86 | 0.074 | 0.6493 | 16 |
| M6 | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | – | – | – | * | – | – | 2721.7 | 1.06 | 0.068 | 0.5893 | 16 |
| M7 | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | – | * | * | – | – | 2721.6 | 1.03 | 0.068 | 0.596 | 18 |
| M8 | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | – | * | – | – | – | – | 2722.0 | 1.38 | 0.057 | 0.5007 | 16 |
| M9 | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | – | – | – | – | 2722.1 | 1.48 | 0.055 | 0.4773 | 17 |
| M10 | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | – | – | * | * | – | – | 2722.2 | 1.65 | 0.050 | 0.4391 | 17 |
| M11 | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | – | – | – | 2722.3 | 1.72 | 0.049 | 0.4242 | 18 |
| M12 | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | – | * | * | – | – | – | 2722.5 | 1.88 | 0.045 | 0.3897 | 17 |
| M13 | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | – | * | – | * | – | – | 2722.7 | 2.15 | 0.039 | 0.3409 | 17 |
| M14 | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | – | * | – | – | 2722.8 | 2.23 | 0.038 | 0.3284 | 18 |
| M15 | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | – | – | 2723.0 | 2.44 | 0.034 | 0.2949 | 19 |
| M16 | * | * | * | * | * | * | * | * | * | * | * | * | * | * | * | – | * | * | * | – | – | 2723.2 | 2.63 | 0.031 | 0.2687 | 18 |

## Results and Discussion

### Double -Observer Sightability Models

We updated the DO-S models based on 145 DO-S trials associated with groups of elk containing radio-collared elk (45 in OLYM and 100 in MORA) and 1,216 DO trials based on groups without radiocollared elk (213 in OLYM and 1,003 in MORA) acquired from 2008 to 2013.

We used Akaike's Information Criterion for small sample size ($AIC_c$) to evaluate model support among the 16 candidate models (Burnham and Anderson, 2002). Support ranged from 3.1 to 11.5percent of the total model weight (table 2).

Of the four parameters tested in the final candidate set, all had modest support ranging from 35 percent for the additive effect of vegetation on back-seat observers to 54 percent for the additive effect of motion on back-seat observers. The additive effects for vegetation and back-seat observers at OLYM had intermediate support (45 and 41percent, respectively). The direction of most effects matched *a priori* expectations. Heterogeneity was positive, indicating that the groups detected by helicopter observers were slightly more detectable than the random sample with radio collars, although this effect was somewhat reduced in OLYM. Sighting probability was higher in OLYM for larger groups (LnN) and with flat lighting (L), but lower for greater vegetation cover (V), for back-seat observers (B), and for front-seat observers when groups were on the pilot's side (P) and even more so when the pilot was an inexperienced observer (IXP). The negative effect of vegetation was substantially reduced when lighting was flat (V*L). The negative effect of vegetation was slightly reduced for back-seat observers relative to front-seat observers (B:V) and also reduced for all observers in OLYM relative to MORA (O:V). Back-seat observers had lower sighting probabilities in OLYM than MORA (O:B).

The effects of motion were somewhat unexpected and were  a complex interaction of motion with park, seat location, and group size. The main effect of motion (M) was to make moving groups less likely to be seen, but this effect was several times stronger (more negative) in OLYM than in MORA (O:M). This difference between parks may be related to the more recent helicopter capture operations conducted in OLYM than in MORA, which may have caused elk to move evasively in response to the helicopter before detection. If this hypothesis is correct, then the negative effect of movement on detection probability in OLYM is expected to decrease in the future now that all aerial elk capture operations have been completed in OLYM. The effect of movement was not as strongly negative for back-seat observers as for front-seat observers (B:M). The positive effect of group size (LnN) was even stronger for moving groups (M*LnN). For some larger groups, this positive effect of motion outweighed the negative effects for smaller groups, making large moving groups easier to detect than similarly sized stationary groups.

We made inferences about population size using weighted-averages across all 16 models in the final set. The model parameters for each of the 16 candidate models are shown in table 3, along with the model weighted value of each parameter.

The model will be updated again following the completion of additional surveys and detectability trials in both parks during 2014 and 2015 elk population surveys. The updated models will be used to compute elk abundance values before examining elk population trends in the high elevation summer ranges of both parks.

**Table 3.** Coefficient estimates for each of the 16 contributing models used in model averaging.

[Models are in ranked order of model support. **Parameter name** explanations are shown in table 1. Coefficients not included in a given model are highlighted in gray and have values of 0.0 for that model. The last row on this table presents the $AIC_c$ model weights, $w_k$, used in model averaging. The last column presents the parameter estimates after model-averaging over the 16 models. Of the 21 parameters initially considered, after preliminary analysis 14 were included in all final 16 used for model inference, 2 were excluded from the final model set, and 4 were considered in all possible combinations leading to the 16 alternative parameterizations]

| | Parameter name | Coefficient estimate | | | | | | | | | | | | | | | | Average estimate |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M1 | M2 | M3 | M4 | M5 | M6 | M7 | M8 | M9 | M10 | M11 | M12 | M13 | M14 | M15 | M16 | |
| 1 | Int | -0.142 | -0.163 | -0.163 | -0.22 | -0.182 | -0.240 | -0.240 | -0.127 | -0.116 | -0.259 | -0.136 | -0.145 | -0.204 | -0.193 | -0.213 | -0.223 | -0.181 |
| 2 | OLYM | 0.592 | 0.727 | 0.592 | 0.904 | 0.710 | 0.901 | 1.036 | 0.595 | 0.594 | 1.017 | 0.730 | 0.717 | 0.903 | 0.905 | 1.046 | 1.030 | 0.777 |
| 3 | Heter | 0.463 | 0.467 | 0.458 | 0.496 | 0.461 | 0.491 | 0.500 | 0.463 | 0.466 | 0.494 | 0.470 | 0.466 | 0.496 | 0.499 | 0.504 | 0.499 | 0.477 |
| 4 | O:Hetero | -0.183 | -0.187 | -0.183 | -0.34 | -0.185 | -0.342 | -0.345 | -0.185 | -0.184 | -0.342 | -0.187 | -0.186 | -0.343 | -0.344 | -0.348 | -0.346 | -0.250 |
| 5 | LnN | 0.402 | 0.402 | 0.402 | 0.402 | 0.402 | 0.401 | 0.402 | 0.402 | 0.402 | 0.401 | 0.403 | 0.402 | 0.401 | 0.402 | 0.402 | 0.401 | 0.402 |
| 6 | P | -0.751 | -0.759 | -0.746 | -0.75 | -0.754 | -0.743 | -0.757 | -0.750 | -0.753 | -0.751 | -0.762 | -0.758 | -0.747 | -0.75 | -0.759 | -0.755 | -0.752 |
| 7 | IXP | -1.021 | -0.986 | -1.012 | -1.02 | -0.979 | -1.015 | -0.989 | -1.008 | -1.018 | -0.982 | -0.982 | -0.974 | -1.01 | -1.02 | -0.984 | -0.976 | -1.001 |
| 8 | C | -4.442 | -4.404 | -4.456 | -4.48 | -4.423 | -4.492 | -4.439 | -4.454 | -4.442 | -4.457 | -4.405 | -4.422 | -4.489 | -4.478 | -4.439 | -4.455 | -4.447 |
| 9 | L | 0.084 | 0.085 | 0.085 | 0.100 | 0.085 | 0.100 | 0.100 | 0.085 | 0.084 | 0.101 | 0.085 | 0.085 | 0.100 | 0.100 | 0.101 | 0.101 | 0.091 |
| 10 | Back | -0.221 | -0.183 | -0.171 | -0.220 | -0.133 | -0.169 | -0.182 | -0.255 | -0.282 | -0.132 | -0.245 | -0.219 | -0.253 | -0.281 | -0.246 | -0.219 | -0.206 |
| 11 | M | -0.316 | -0.324 | -0.165 | -0.340 | -0.165 | -0.190 | -0.348 | -0.165 | -0.306 | -0.189 | -0.313 | -0.165 | -0.189 | -0.331 | -0.338 | -0.189 | -0.256 |
| 12 | V | -1.837 | -1.837 | -1.835 | -1.680 | -1.836 | -1.675 | -1.676 | -1.962 | -1.935 | -1.676 | -1.938 | -1.967 | -1.802 | -1.773 | -1.778 | -1.808 | -1.811 |
| 13 | O:M | -1.224 | -1.238 | -1.223 | -1.180 | -1.224 | -1.182 | -1.197 | -1.225 | -1.225 | -1.183 | -1.240 | -1.227 | -1.183 | -1.184 | -1.199 | -1.185 | -1.211 |
| 14 | M*LnN | 0.304 | 0.305 | 0.302 | 0.313 | 0.302 | 0.311 | 0.314 | 0.302 | 0.305 | 0.311 | 0.306 | 0.302 | 0.311 | 0.314 | 0.315 | 0.311 | 0.307 |
| 15 | V*L | 0.321 | 0.343 | 0 | 0.323 | 0 | 0 | 0.344 | 0 | 0.297 | 0 | 0.318 | 0 | 0 | 0.299 | 0.319 | 0 | 0.174 |
| 16 | B:M | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.267 | 0.207 | 0 | 0.214 | 0.278 | 0.267 | 0.206 | 0.221 | 0.284 | 0.084 |
| 17 | M*V | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.000 |
| 18 | O:B | 0 | -0.265 | 0 | 0 | -0.240 | 0 | -0.264 | 0 | 0 | -0.239 | -0.268 | -0.247 | 0 | 0 | -0.271 | -0.249 | -0.115 |
| 19 | O:V | 0 | 0 | 0 | -0.630 | 0 | -0.627 | -0.628 | 0 | 0 | -0.622 | 0 | 0 | -0.627 | -0.633 | -0.637 | -0.633 | -0.256 |
| 20 | O:L | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.000 |
| 21 | V*L | -0.142 | -0.163 | -0.163 | -0.220 | -0.182 | -0.240 | -0.240 | -0.127 | -0.116 | -0.259 | -0.136 | -0.145 | -0.204 | -0.193 | -0.213 | -0.223 | -0.181 |
| **Model weight** | | 11.5% | 10.0% | 9.9% | 7.9% | 7.4% | 6.8% | 6.8% | 5.7% | 5.5% | 5.0% | 4.9% | 4.5% | 3.9% | 3.8% | 3.4% | 3.1% | |

## Abundance Estimates

Population estimates of elk within each of the trend count areas (TCA) are provided in tables 4 and 5. TCAs are defined in Griffin and others (2012). Minor differences in estimates reported here versus those estimated in previous reports (Griffin and others, 2013; Jenkins and others, 2015) reflect both changes in the models resulting from increased numbers of DO trials and the addition of OLYM parameters in the model. Composition ratio estimates for all sex and age classes of elk are provided in appendix A.

**Table 4.** Raw elk counts and estimated elk abundance ($\bar{\bar{N}}_{a,t}$) in surveyed trend count area, *a*, during year, $t$, and associated standard error (SE) in Olympic National Park, 2008–13.

[Percent seen was estimated as the raw count divided by $\bar{\bar{N}}_{a,t}$]

| Trend count area | Year | Replicate | Raw count | $\bar{\bar{N}}_{a,t}$ | SE($\hat{N}$) | Percent seen |
|---|---|---|---|---|---|---|
| Core | 2008 | 1 | 263 | 292 | 26.4 | 90.0 |
| | 2011 | 1 | 237 | 255 | 26.9 | 93.1 |
| | 2012 | 1 | 348 | 372 | 27.8 | 93.6 |
| | 2013 | 1 | 241 | 273 | 20.2 | 88.3 |
| | $\bar{x}$ | | | 298 | 51.0 | 91.4 |
| Elwha | 2012 | 1 | 76 | 92 | 20.6 | 82.3 |
| Northwest | 2008 | 1 | 83 | 88 | 16.8 | 94.7 |
| | 2011 | 1 | 18 | 21 | 3.3 | 86.7 |
| | 2012 | 1 | 228 | 229 | 1.6 | 99.5 |
| | $\bar{x}$ | | | 113 | 17.2 | 97.5 |
| Quinault | 2008 | 1 | 3 | 3 | 1.2 | 92.3 |
| | 2011 | 1 | 169 | 179 | 22.8 | 94.3 |
| | $\bar{x}$ | | | 91 | 22.8 | 94.3 |
| Southeast | 2013 | 1 | 90 | 98 | 10.6 | 91.9 |

**Table 5.** Raw elk counts and estimated elk abundance ($\bar{\bar{N}}_{a,t}$) in surveyed trend count areas (TCAs) ($a$) during year $t$, and associated standard error (SE) in Mount Rainier National Park, 2008–13.

[Percent seen was estimated as the raw count divided by $\bar{\bar{N}}_{a,t}$]

| TCA | Year | Replicate | Raw count | $\bar{\bar{N}}_{a,t}$ | SE($\hat{N}$) | Percent seen |
|---|---|---|---|---|---|---|
| North | 2008 | 1 | 221 | 246 | 16.7 | 89.7 |
| | | 2 | 248 | 297 | 31.6 | 83.4 |
| | 2009 | 1 | 365 | 428 | 27.3 | 85.2 |
| | 2010 | 1 | 290 | 310 | 12.6 | 93.5 |
| | | 2 | 375 | 415 | 22.2 | 90.3 |
| | 2011 | 1 | 373 | 426 | 52.7 | 87.5 |
| | | 2 | 268 | 313 | 29.9 | 85.7 |
| | 2012 | 1 | 233 | 283 | 30.8 | 82.2 |
| | 2013 | 1 | 247 | 313 | 44.5 | 78.8 |
| | | 2 | 106 | 174 | 22.7 | 60.9 |
| | $\bar{x}$ | | | 321 | 98.9 | 85.0 |
| South | 2008 | 1 | 349 | 448 | 49.0 | 77.8 |
| | | 2 | 291 | 378 | 48.9 | 77.0 |
| | 2009 | 1 | 397 | 501 | 57.7 | 79.2 |
| | | 2 | 225 | 280 | 25.1 | 80.2 |
| | 2010 | 1 | 612 | 706 | 41.2 | 86.7 |
| | | 2 | 327 | 401 | 35.1 | 81.4 |
| | 2011 | 1 | 538 | 683 | 68.3 | 78.8 |
| | 2012 | 1 | 706 | 833 | 83.3 | 84.7 |
| | | 2 | 495 | 619 | 50.6 | 80.0 |
| | 2013 | 1 | 501 | 609 | 59.3 | 82.2 |
| | $\bar{x}$ | | | 546 | 171.4 | 81.3 |

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# Appendix A. Abundance Estimates of Sex and Age Classes of Elk in Each of the Survey Units in Olympic and Mount Rainier National Parks, 2008–13

[Arithmetic means of estimated (Est) values for each trend count area (TCA) are shown as $\bar{x}$. For each ratio, the standard error of the mean (SE) is provided]

| Park | TCA | Year | Replicate | Calves: 100 cows | | Total Bulls: 100 cows | | Spike Bulls: 100 cows | | Subadult Bulls: 100 cows | | Mature Bulls: 100 cows | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Est | SE | Est | SE | Est | SE | Est | SE | Est | SE |
| OLYM | Core | 2008 | 1 | 38 | 1.5 | 59 | 7.5 | 5 | 0.8 | 4 | 0.6 | 50 | 7.1 |
| | | 2011 | 1 | 29 | 1.7 | 57 | 7.8 | 6 | 1.1 | 9 | 1.5 | 42 | 6.5 |
| | | 2012 | 1 | 34 | 0.6 | 60 | 6.7 | 6 | 0.4 | 5 | 0.7 | 48 | 6.6 |
| | | 2013 | 1 | 35 | 2.0 | 65 | 8.3 | 3 | 0.4 | 8 | 1.5 | 54 | 8.1 |
| | | $\bar{x}$ | | 34 | 3.1 | 60 | 15.2 | 5 | 1.5 | 7 | 2.3 | 48 | 14.2 |
| | Elwha | 2012 | 1 | 25 | 3.7 | 114 | 56.3 | 14 | 2.8 | 17 | 14.2 | 84 | 45.0 |
| | Northwest | 2008 | 1 | 33 | 3.7 | 24 | 8.2 | 6 | 0.6 | 2 | 0.2 | 17 | 8.8 |
| | | 2011 | 1 | 13 | 1.9 | 115 | 40.2 | 13 | 1.9 | 0 | 0.0 | 102 | 41.4 |
| | | 2012 | 1 | 45 | 0.0 | 15 | 1.6 | 1 | 0.0 | 2 | 0.0 | 12 | 1.6 |
| | | $\bar{x}$ | | 30 | 4.2 | 51 | 41.1 | 6 | 2.0 | 1 | 0.2 | 43 | 42.4 |
| | Quinault | 2011 | 1 | 29 | 1.4 | 47 | 6.2 | 0 | 0.0 | 12 | 1.8 | 35 | 5.4 |
| | Southeast | 2013 | 1 | 33 | 1.5 | 63 | 18.1 | 14 | 1.2 | 7 | 1.8 | 42 | 17.1 |

**Appendix A.—**Continued.

| Park | TCA | Year | Replicate | Calves: 100 cows | | Total Bulls: 100 cows | | Spike Bulls: 100 cows | | Subadult Bulls: 100 cows | | Mature Bulls: 100 cows | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Est | SE | Est | SE | Est | SE | Est | SE | Est | SE |
| MORA | North | 2008 | 1 | 47 | 1.8 | 34 | 5.7 | 12 | 1.6 | 6 | 2.3 | 17 | 3.4 |
| | | | 2 | 44 | 2.6 | 40 | 3.3 | 18 | 2.2 | 7 | 1.0 | 15 | 2.1 |
| | | 2009 | 1 | 38 | 1.3 | 29 | 3.6 | 1 | 0.2 | 9 | 1.5 | 19 | 3.1 |
| | | 2010 | 1 | 33 | 0.9 | 49 | 5.2 | 4 | 0.8 | 7 | 1.6 | 37 | 4.4 |
| | | | 2 | 50 | 2.1 | 46 | 3.5 | 10 | 0.7 | 9 | 1.8 | 27 | 3.4 |
| | | 2011 | 1 | 36 | 1.8 | 55 | 7.5 | 12 | 2.2 | 20 | 4.2 | 23 | 4.1 |
| | | | 2 | 25 | 1.9 | 26 | 5.0 | 6 | 1.4 | 6 | 1.9 | 14 | 3.2 |
| | | 2012 | 1 | 49 | 2.8 | 49 | 5.1 | 12 | 1.0 | 17 | 2.8 | 21 | 3.0 |
| | | 2013 | 1 | 47 | 3.9 | 42 | 7.9 | 6 | 1.8 | 6 | 1.6 | 30 | 6.4 |
| | | | 2 | 35 | 5.5 | 40 | 6.7 | 0 | 0.0 | 22 | 5.0 | 18 | 3.5 |
| | | $\bar{x}$ | | 41 | 8.8 | 41 | 17.6 | 8 | 4.4 | 11 | 8.4 | 22 | 12.1 |
| | South | 2008 | 1 | 35 | 1.8 | 34 | 3.5 | 10 | 1.4 | 10 | 1.6 | 14 | 1.8 |
| | | | 2 | 32 | 2.4 | 37 | 4.3 | 6 | 1.1 | 11 | 2.3 | 19 | 2.7 |
| | | 2009 | 1 | 35 | 1.7 | 34 | 5.4 | 5 | 0.6 | 11 | 2.4 | 18 | 3.5 |
| | | | 2 | 34 | 2.4 | 29 | 5.5 | 1 | 0.0 | 4 | 1.3 | 24 | 5.3 |
| | | 2010 | 1 | 32 | 1.1 | 33 | 2.3 | 4 | 0.4 | 11 | 1.0 | 18 | 1.9 |
| | | | 2 | 39 | 2.1 | 52 | 7.4 | 1 | 0.3 | 8 | 1.4 | 44 | 6.8 |
| | | 2011 | 1 | 35 | 1.9 | 50 | 4.3 | 7 | 0.9 | 25 | 2.9 | 19 | 2.0 |
| | | 2012 | 1 | 36 | 1.4 | 42 | 4.7 | 5 | 0.7 | 11 | 1.5 | 26 | 3.5 |
| | | | 2 | 40 | 2.4 | 47 | 4.3 | 11 | 1.4 | 20 | 2.5 | 17 | 2.5 |
| | | 2013 | 1 | 30 | 2.0 | 38 | 5.0 | 3 | 0.5 | 4 | 0.8 | 32 | 4.8 |
| | | $\bar{x}$ | | 35 | 6.2 | 40 | 15.3 | 5 | 2.7 | 11 | 6.0 | 23 | 12.1 |